AD-A052 661 NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF F/G 5/3
AN ECONOMIC ANALYSIS OF LIFE CYCLE MILITARY MANPOWER MAINTENANC--ETC(U)
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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

(6) An Economic Analysis of Life Cycle Military Manpower Maintenance and Training Requirements in Avionics Minicomputer and Microcomputer Systems.

by

(9) Master's thesis

(10) Dennis Harry Genovese

(11) Mar[redacted]978 (12) 68P.

Thesis Advisor: J. D. Buttinger

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251 450 JOB

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Economic Analysis of Life Cycle Military Manpower Maintenance and Training Requirements in Avionics Minicomputer and Microcomputer Systems		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis March 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dennis Harry Genovese		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93940		12. REPORT DATE March 1978
		13. NUMBER OF PAGES 67
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, CA 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Minicomputer	Maintenance
Microcomputer	Training
Federated Computer System	Avionics
Life Cycle Cost	Consolidated Computer System

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The dramatic advances within the electronics industry over the last few decades have brought about several equally effective computer design alternatives for use in military avionics systems. This report is an attempt to examine the maintenance personnel and training Life Cycle Costs associated with three of these alternatives; (1) Consolidated Mission Computer, (2) Federated Homogeneous Computer System, and (3) Federated Heterogeneous

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(Page 1) S/N 0102-014-6601 |

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (continued)

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An Economic Analysis of Life Cycle Military Manpower Maintenance and Training Requirements in Avionics Minicomputer and Microcomputer Systems

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1978

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ABSTRACT

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I. EXECUTIVE SUMMARY

A. BACKGROUND

The recent technological advances in the electronics industry have radically changed the economics of Automatic Data Processing Equipment (ADPE). This economic change is of significant importance in determining which of several design alternatives, equivalent in computer effectiveness, is chosen for future military avionics applications. The use of integrated circuits (IC), in particular large scale integration (LSI), has produced three major applicable design alternatives for which economic cost computation and comparison would appear to be the most significant.

The first alternative is the use of a consolidated computer system. This would be accomplished through the application of a single minicomputer, a so-called mission computer, which is a general purpose computer for performing all avionics required functions with a minimum of additional processing equipment. This type of system is currently available from several manufacturers such as Keronix Incorporated, Control Data Corporation, Rolm Corporation, Norden Division of United Technologies Corporation, and Digital Equipment Corporation. There are several militarized versions of the minicomputer available from the various manufacturers in the AN/AYK-14, AN/AYK-19, and several others. The use of a consolidated system is presently employed in many of the Naval aircraft already in the field.

The second alternative design approach is the use of a federated homogeneous computer system. This would entail the use of up to "ten" identical microcomputers, each performing a separate avionics function or sub-function. The number ten is used to account for all of the avionics functions required to be performed in any aircraft system as well as control of the distributed network system.

The use of microcomputers is also the basis for the third alternative with one major difference. The third alternative would consist of a federated heterogeneous computer system. This would be comprised of up to ten microcomputers, each possibly different in physical design. This would allow for hardware design alternatives appropriate for each avionics function. These design alternatives would be accomplished through computer software/firmware in alternative two.

Microcomputers are also available from several manufacturers, including Intel Corporation, Digital Equipment Corporation, and Hughes Aircraft Corporation. One military version, the AN/UYK-30, is currently available from Hughes Aircraft Corporation, with another version, the LSI-11M becoming available from Norden Division in December 1977.

B. MAINTENANCE POLICY

The overall complexity of the new technology and the need for aircraft "up-time" dictates the assumption of the following maintenance policy in the study. Organizational maintenance, at the aircraft squadron level, will consist of fault isolation with subsequent module removal and replacement.

This entails the replacement of a component assembly board in alternative one and replacement of the entire microcomputer in alternatives two and three. In all three alternatives the replacement is accomplished with an off-the-shelf spare. It is also assumed that the built-in software tests (BIT) inherent in each of the alternatives foregoes the need for preventative maintenance except for the BIT. The physical characteristics of IC and LSI technologies do not allow for the identification of impending hardware failures as was previously available in the discrete component and core memory technologies.

Intermediate level maintenance will be assumed to consist of the repair of the faulty components removed at the organizational level. This will be examined for all of the alternatives as well as examining the repair vs. discard in case of the microcomputers.

C. TRAINING

Training requirements and associated life cycle cost calculations will be based on current averages of aviation manning levels. The relatively short economic life, eight years, of ADPE, combined with the lengthy time lag between project inception and military training program development, and the changing "state of the art," dictate the use of commercial training through the life of the equipment. The relevant tuition costs will be based on currently available commercial courses.

D. ANALYSIS

An "a fortiori" analysis was used to evaluate the three alternatives. This was accomplished by deliberately biasing the available reliability and repair data in favor of the first and already existing alternative, a central single mission computer. This was also included in the determination of the figure of "ten" microcomputers in alternatives two and three. This figure is deliberately a high estimation, as all of the research data was not complete at the time of this writing.

The life cycle cost elements that were considered were based upon the publication "Cost Effectiveness Program for Joint Tactical Communications (TRI-TAC), October 1976, by the Joint Tactical Communications Office, Fort Monmouth, New Jersey. The only elements considered were those applicable to hardware maintenance and training costs, as outlined in Appendix B. These elements are a subset of the total life cycle cost model as outlined in Appendix A.

E. CONCLUSIONS

Yearly training and maintenance costs were calculated for each of the three alternatives, which were subsequently discounted to a present value figure using the discount rate of 10% as prescribed by government regulation. The following figures were the result:

ALTERNATIVE 1 Consolidated Minicomputer	$1,642,324
ALTERNATIVE 2 Federated Homogeneous Microcomputers	$544,308

ALTERNATIVE 3 Federated Heterogeneous Microcomputers	\$592,423

These calculations are based on the use of the equipment in six aircraft squadrons and one intermediate maintenance facility. The approximate $50K difference between alternatives two and three is caused by discarding components in alternative two instead of repair. This is economically sound only in this alternative.

The analysis indicates that the microcomputer alternative is significantly less costly than the minicomputer approach. The difference between alternatives two and three is not nearly as significant. Application of the alternatives in a Navy-wide program would change the absolute figures considerably. Exploration of relative percentage differences is an area studied in the wider research effort as previously identified. Consideration of the other elements in the total life cycle cost of the alternatives is necessary to obtain conclusive findings, particularly in the computer software area.

II. INTRODUCTION

The rapid technological advances in the electronics industry during the past three decades have caused dramatic reductions in the cost of Automatic Data Processing Equipment (ADPE). The development of integrated circuits (IC), in particular Large Scale Integration (LSI), has made possible computer designs quite different from the large scale computer systems previously available.

Computer technology has become "state-of-the-art" in nearly every imaginable application. Hardware and associated software systems are now available in sizes ranging from room-size large scale systems to hand held calculators. The new smaller computers, known as "mini" or "micro" computers, have allowed the introduction of equally effective systems for identical applications with completely different designs. This paper will attempt to examine the associated Life Cycle Cost of several design alternatives for one particular application, ADPE in military aircraft avionics systems.

First, a brief history of the computer industry and the development of mini and micro computers will be presented. Next, the characteristics and reasoning behind an economic analysis will be discussed. This will encompass background information of life cycle cost as well as the rationale for researching only a partial system cost. Finally, the analysis will be presented, including the assumptions used and a discussion of the results.

III. HISTORY

The end of WWII marked the beginning of a revolution within the electronics industry, one that this writer is sure we have just begun. While automatic machines have been an integral part of our society for years, a programmable machine that can solve extremely difficult mathematical problems in microseconds, allocate telephone lines as demanded, or process millions of words of data in a few seconds, has been a development of the past few decades.

Computer circuit technology has evolved from the use of bulky and inefficient vacuum tubes, through the use of discrete components such as transistors, diodes, and resistors to the age of integrated circuits (IC). In the early 1960's the commercially available IC's incorporated at most a score of discrete components. The production yield, fraction of circuits that worked, was very low and the available packaging technology did not allow the realization of practical devices with more than a dozen connections. The technology was so amiable to improvement and the rivalry among manufacturers was so keen that every year since, the number of components that could be placed on a single silicon chip has doubled. Today, IC's less than a quarter of an inch per side can incorporate up to 20,000 separate components, carry over 100 individual circuits, and have over 80 separate and practical connections. This evolution in electronic circuitry has appropriately been termed Large Scale Integration (LSI).

The steady increase in component density made possible the development of the minicomputer. The typical minicomputer is a parallel data processor that employs IC's and is housed in a compact cabinet suitable for either table-top use as a single complete device or in a cabinet with other electronic equipment. Minicomputers have greatly reduced the costs of computing and/or information processing as well as offering a very flexible and simplified design alternative to the large main frame computer system. More importantly, they made possible a wide range of new applications that called for an inexpensive resident computer. They have found their way into many American homes with the introduction of simpler readily available models to the public, that are no more expensive than the average color TV set.

With the continuing advances in microelectronics, it was felt to be just a question of time until the further integration of microscopic components would lead to the development of the microcomputer, a machine that would require at most a few chips and consume no more than a few hundred milliwatts of power. In the late 1960's the electronics industry was concentrating on bipolar devices, those with both "holes" and electrons for current carriers. The industry was plagued with problems of heat dissipation and low production yields. Due to these and other problems, the search began for an alternative design, leading to the birth of metal-oxide-semiconductors (MOS), and the solution of major problems. It became economically feasible to manufacture large unipolar devices with both high component densities and low heat production.

The development of MOS technology contributed to a major conceptual advance in 1971, when Intel Corporation which had undertaken to develop a calculator chip, chose to design it as a more versatile, programmable, single-chip microprocessor. (A microprocessor is analogous to a central processing unit of a large main frame computer.) The inclusion of a control memory and a master timing clock led to the birth of the microcomputer.

Microcomputers lie somewhere between microprocessors and minicomputers, presenting a viable alternative to each. They are available in several packages ranging from ones with switches and lights as in the minicomputer to single board systems that can be held in the palm of the hand. Furthermore, the microcomputer does not require an integral power supply as does the minicomputer, but can share the same power supply with many other devices, a definite advantage for the microcomputer.

The introduction of LSI has also led to the development of high cost custom designed LSI's. These high costs are directly attributable to the development costs and the required amortization of these costs to the equipment. The employment of versatile LSI's in microcomputers has greatly reduced this cost through the use of several optional memory systems ranging from "read-only-memory" to "erasable-programmable-memories," known as ROM and EPROM, respectively. The economic advantage of this design is easily seen.

Until recently, digital circuits were designed almost exclusively with hardwired logic. The strides gained by the

use of printed-circuit boards and metallized paths were powerful tools, but the introduction of the various memory options has allowed a much more flexible product that can be modified or improved without a redesign of the hardware. The use of microcomputers and minicomputers is common in the electronics field of today. They are both state-of-the-art designs and both capable of many diverse applications. The choice among the two, and even within each type for an appropriate choice, must rest on the desired application and the economics of the individual situation.

IV. ECONOMIC ANALYSIS

A. WHAT IS AN ECONOMIC ANALYSIS?

Every manager devotes considerable time and effort to planning for the future, whereby virtually every plan is primarily concerned with the allocation of scarce resources. The method of approaching a complex problem of choice among resource allocation decisions is called Economic Analysis. This form of analysis examines the basic problem of economic choice, a problem of major concern within the Department of Defense.

Economic analysis is performed in two general formats. The first format is known as cost-benefit analysis which compares the associated costs and benefits that would be incurred as a result of a possible future decision. This type of analysis facilitates the development of economic criterion as a basis for input to the final yes or no decision. The decision would not be made solely on the basis of the analysis, but the economic analysis is a very strong input.

The second format, the one used in this study, is known as cost-effectiveness analysis. This format is used to evaluate alternative systems to satisfy one of two possible objectives; (1) maximum effectiveness for a fixed cost or (2) minimum cost for a fixed level of effectiveness. This paper will examine several equally effective alternatives and attempt to determine the least cost alternative through the use of a Life Cycle Cost (LCC) model.

B. WHAT IS LIFE CYCLE COST?

Total life cycle cost of an equipment or system consists of the total cost of acquisition and ownership of that equipment or system over its full economic life. It includes research and development, investment, and operation costs.

1. Research and Development Costs

Those program development costs associated with the development of a new or improved capability to the point where it is ready for procurement and operational use. These costs include costs for initial research and development of the equipment, prototype development and procurement, prototype installation, test and evaluation, and the management and support necessary to accomplish these tasks.

2. Investment Costs

Those program costs required beyond R&D to introduce into operational use a new capability, or to procure initial, additional or replacement equipment for operating forces. Investment costs include equipment procurement, new facilities, installation, initial spares and support equipment such as test equipment.

3. Operating Costs

Those recurring program costs required to operate and maintain the capability as well as the costs associated with introducing improvement(s) to extend or improve the equipment service life. Operating costs include those costs for personnel pay and allowances, equipment maintenance, personnel training, logistics support and consumables.

Differential life cycle costs of an equipment or system are the relevant life cycle costs which must be evaluated when a comparison between alternative equipments or systems is desired. This study will examine the differential life cycle costs of several alternatives by computation of partial LCC within the category of operating costs.

C. WHY DEVELOP PARTIAL LIFE CYCLE COSTS?

Although total system life cycle cost is developed by the computation of all categories of cost, history has shown that the operating costs contribute over 50% of the total by the end of the system's economic life. This paper will examine those costs associated with the hardware maintenance personnel and training costs. This will be accomplished through the selection of those cost elements directly traceable to these areas (Appendix B). This phenomenon is demonstrated in Figure 1.

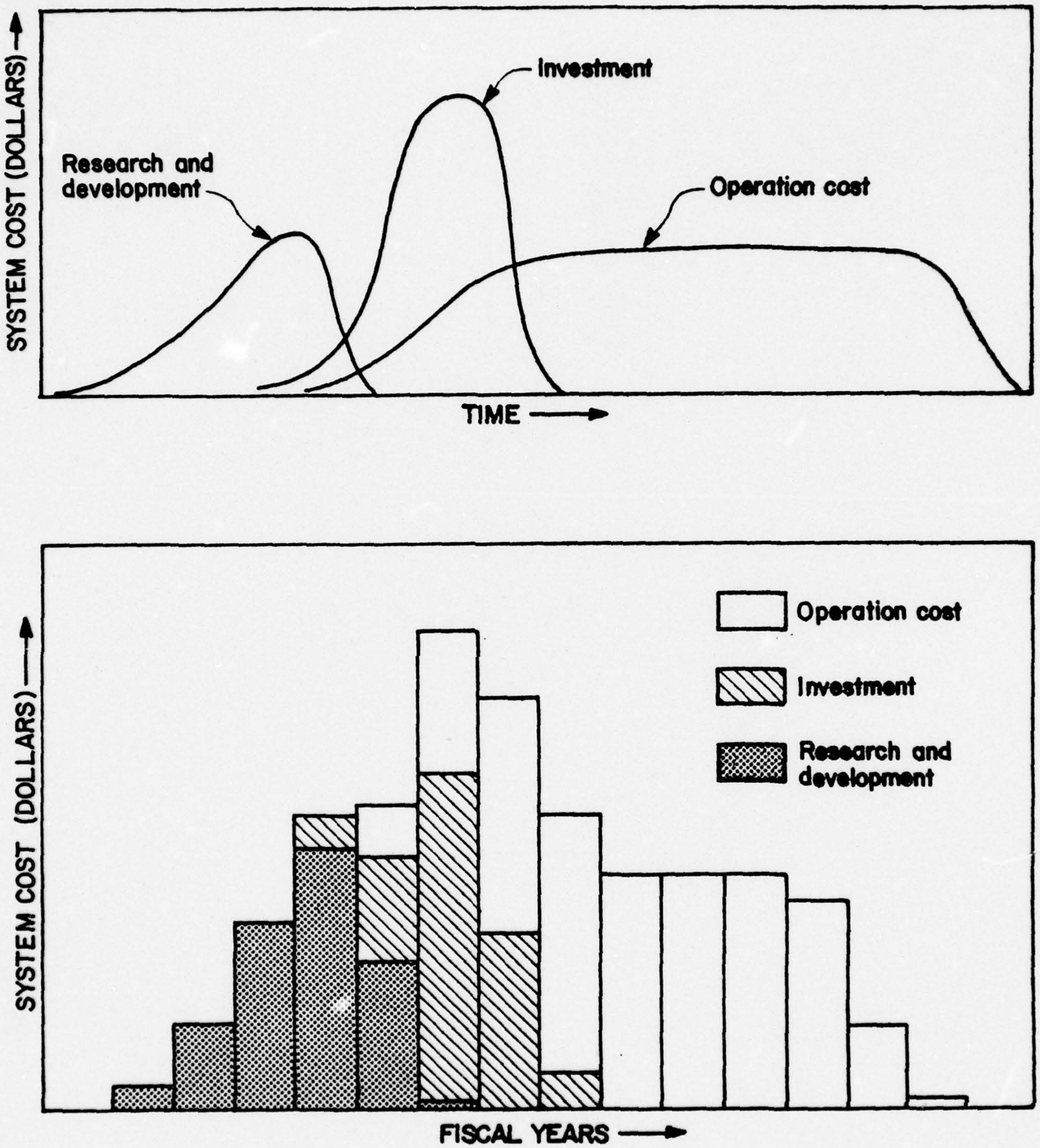
SYSTEM COST (DOLLARS)
Investment
Research and development
Operation cost
TIME
Operation cost
Investment
Research and development
FISCAL YEARS

FIGURE 1.

V. COST ELEMENT IDENTIFICATION

A. PURPOSE

The purpose of this chapter is to identify and classify cost elements applicable to maintenance personnel and training costs in the overall heading of operating costs. The determination concerning a specific cost element's applicability to this particular category is of course judgemental. The elements considered are outlined in Figure 2, which comprises a subset of the total life cycle cost model as outlined in Appendix A [3].

B. ASSUMPTIONS

Assumptions pertinent to the development of the algorithm for this study are specified for reference below.

(1) Organizational level maintenance will consist of fault isolation with subsequent module removal and replacement. In alternative one, this would consist of the removal and replacement of a component board such as the central processing unit board, the memory board, or the multiplexer board. In alternatives two and three, this consists of the removal and replacement of the entire microcomputer. In all three alternatives the replacement is accomplished with an off-the-shelf spare. This assumption is based on the overall complexity of the LSI and IC technologies as well as the need for aircraft "up-time." This pertains to the corrective maintenance procedure at the organizational level.

I. INITIAL STUDENT TRAINING

   A. OPERATOR TRAINING

   B. INSTRUCTOR TRAINING

   C. MAINTENANCE TRAINING

II. MAINTENANCE PERSONNEL

   A. ORGANIZATIONAL LEVEL

   B. INTERMEDIATE LEVEL

III. SUPPORT EQUIPMENT MAINTENANCE

   A. ORGANIZATIONAL LEVEL

   B. INTERMEDIATE LEVEL

IV. SPARE PARTS

COST ELEMENTS CONSIDERED

FIGURE 2

(2) Organizational level maintenance will consist of corrective maintenance only. Periodic maintenance will not be performed due to the Built In Tests (BIT) inherent in the hardware technology. The software systems within each alternative will perform periodic checks on the hardware when not processing data. The technology does not allow for identification of impending faulty hardware as in the case of discrete component and core memory technologies.

(3) The cost elements to be considered will be chosen from the total life cycle cost model developed by the Joint Tactical Communications Office, Fort Monmouth, New Jersey (TRI-TAC) [3].

(4) The hardware maintenance required will be performed at both the organizational and intermediate levels by the Aviation Electronics Technician (AT) rating. The necessary general skills are proficient in the Second Class Petty Officer and above [4].

(5) Maintenance requirements will be formulated on the average aircraft squadron size of nine aircraft, and the Intermediate Maintenance Department serving an average of six squadrons.

(6) Manpower costs will be based upon the 1977 data available from the Bureau of Naval Personnel, PERS-2 [5].

(7) The ADPE life cycle will be considered as eight years, as mandated by the Department of Defense [6].

(8) Training course requirements and associated tuition costs will be based on currently available commercial courses of instruction. This assumption, although normally applicable

for initial training, is also valid for the total life cycle in the case of ADPE. The changing state-of-the-art, coupled with the lengthy time lag historically present between project inception and military training program development, dictate that total commercial training be utilized. This concept is employed in many existing military ADPE systems [7,8].

(9) Aircraft flight hours are programmed an average of 65 hours per month. The amount of time that power is applied to the aircraft while in a non-flying status varies tremendously from aircraft to aircraft and is not normally documented. A factor of two times the programmed monthly flight time will be used as an estimate. This will produce a figure of 195 hours for total monthly operating hours. This accounts for ground tests of equipment associated with the computers as well as preflight and postflight equipment checkout times [9].

(10) Training requirements will be assumed constant over the entire life cycle of the equipment. This assumption facilitates development of a figure for yearly training costs over the expected life cycle.

(11) A 10% discount rate will be used in the cost computations [10]. No inflation will be assumed.

(12) The comparison of costs between ten microcomputers and one minicomputer is based on the relative capability or computing power of each. This 10:1 ratio, at most, is biased in favor of the minicomputer, with a smaller ratio possibility, depending on the application.

(13) Maintenance requirements and costs of spare parts are assumed to be constant over time.

C. IDENTIFICATION

The cost elements will be individually examined using the decision process outlined in Figure 3. The elements not excluded in the process will be used in the partial LCC computations for this study.

COST ELEMENT SELECTION DECISION PROCESS

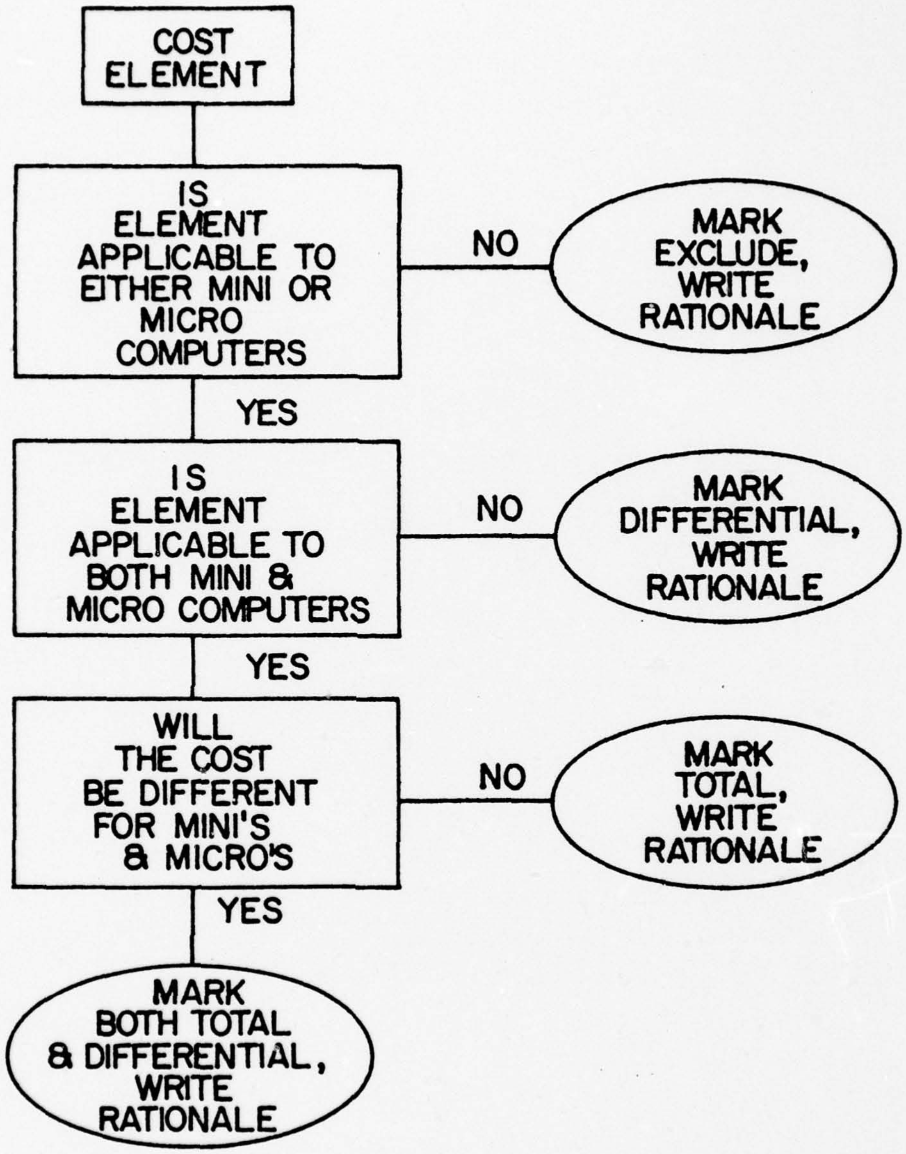

FIGURE 3.

I. Initial Student Training

A. Operator Training

( ) Total
( ) Differential
(X) Excluded

Description

This element represents the cost of training operators for the equipment.

Rationale

Specific operation of either mini or microcomputer will be automatic. The only training necessary would be for operation of equipment utilizing the computers, not for the computers explicitly.

I. Initial Student Training

A. Operator Training

B. Instructor Training

( ) Total
( ) Differential
(X) Excluded

Description

This element represents the cost of training instructor personnel.

Rationale

Instructor training will not be required due to all training being conducted by commercially available courses. (Assumptions 7 and 8)

I. Initial Student Training

A. Operator Training

B. Instructor Training

C. Maintenance Training

(X) Total
(X) Differential
( ) Excluded

Description

This element represents the cost of training maintenance personnel for the equipment.

Rationale

Initial training of both organizational and intermediate level maintenance personnel will be necessary throughout the Life Cycle of the equipment. Training requirements are different for the desired maintenance and for each system type. The microcomputer system requires less training at the organizational level due to the separation of each system, unlike the integrated minicomputer system.

II. Maintenance Personnel

A. Organizational Level

(X) Total
(X) Differential
( ) Excluded

Description

This element includes that portion of the maintenance personnel costs associated with organizational level corrective (emergency) maintenance. (Assumptions 1 and 2) It will consist of fault isolation, removal and replacement of faulty modules.

Rationale

Corrective maintenance must be performed at the organizational level. There will be a differential element in that maintenance repair times will be different between mini and microcomputers. This is due to the relative differences existing between failure rates in the alternative, favoring the microcomputer system [11, 12, 13, 14].

II. Maintenance Personnel

A. Organizational

B. Intermediate

(X) Total
(X) Differential
( ) Excluded

Description

This element includes that portion of maintenance personnel costs associated with the intermediate level maintenance. It will consist of module repair.

Rationale

The requirement for module repair may be cost effective. An analysis of costs associated with repair vs. disposal will be conducted. Differential costs exist between the mini and microcomputers, due to failure rate differences favoring the microcomputer system [11, 12, 13, 14].

III. Support Equipment Maintenance

A. Organizational

(X) Total
(X) Differential
( ) Excluded

Description

This element includes the cost of maintenance and calibration of common and peculiar support equipment.

Rationale

The equipment required to support the microcomputer at the organizational level is peculiar to the microcomputer. The memory type used dictates this requirement [15].

III. Support Equipment Maintenance

A. Organizational

B. Intermediate

(X) Total
( ) Differential
( ) Excluded

Description

This element includes the cost of maintenance and calibration of common and peculiar support equipment at the intermediate level.

Rationale

The support equipment requirements at the intermediate level are identical for both mini and microcomputers.

IV. Spare Parts

( ) Total
(X) Differential
( ) Excluded

Description

This element refers to modules and assemblies used for replacement purposes. This includes parts required at both the intermediate and organizational levels.

Rationale

This element is to be considered in lieu of performing maintenance on unserviceable items, and only replacing with off-the-shelf purchased spares in the homogeneous micro-computer system alternative.

VI. SPECIFIC ELEMENT LIFE CYCLE COST VALUES

A. PURPOSE

The purpose of this chapter is to examine those specific cost elements not excluded in the decision process, outlined in Figure 3, and to determine the specific life cycle cost values of each. The overall figures will be presented, with an in-depth analysis of the computations being presented in Appendix B. The specific elements that will be examined are outlined in Figure 4.

B. SPECIFIC COST VALUES

I. Maintenance Training
   A. Organizational
   B. Intermediate

MINICOMPUTER. The maintenance training requirements for a minicomputer avionics ADPE system are very extensive. The technicians will require a full working knowledge of the hardware system as well as the operating and software system. This is dictated by the fact that the minicomputer will be an integral part of all avionics systems within the aircraft: the common denominator.

Course length and content discussions conducted with the Maintenance Division Supervisor [8] and Engineering Division Supervisor [15] of Fleet Numerical Weather Central, Monterey, CA, coincide with commercial industry recommendations [11, 12, 13, 16]. The applicable course lengths for minicomputer training are eight weeks for the organizational level, and seven

I. MAINTENANCE TRAINING

A. ORGANIZATIONAL

B. INTERMEDIATE

II. MAINTENANCE PERSONNEL

A. ORGANIZATIONAL

B. INTERMEDIATE

III. SUPPORT EQUIPMENT MAINTENANCE

A. ORGANIZATIONAL

B. INTERMEDIATE

IV. SPARE PARTS

ELEMENTS TO BE EXAMINED

Figure 4

weeks for the intermediate level. The requirement at the organizational level is met by extensive hardware and operating system instruction. The seven weeks required for intermediate level is composed of a two week familiarization course and a five week miniature and micro circuit repair course. This five week course is a current NAVAIR requirement for technicians performing this type of circuit repair [17].

MICROCOMPUTER. The maintenance training requirements for a distributed microcomputer avionics system are not as extensive as the requirements for a minicomputer system at the organizational level. The microcomputer will be an integral part of the avionics, but separated so that each will be performing a separate function, as separate entities [18]. The only training requirement will be for a familiarization course including modular removal and replacement. A two week course covering general microcomputer technology will be sufficient.

The intermediate maintenance level training requirements are identical to those of the minicomputer, with a seven week course being required.

The average billet structure existing within the aviation community is displayed in Table I [19].

II. Maintenance Personnel
   A. Organizational
   B. Intermediate

The maintenance personnel requirements for all of the alternatives are directly related to the amount of maintenance required for each system. This was partially discussed in assumptions 1, 2, and 9.

SQUADRON (average of 9 aircraft)

No. of personnel	Rating
1	ATC
3	AT1
8	AT2
6	AT3 and below

INTERMEDIATE MAINTENANCE DEPARTMENT
(average of 1 for every 6 squadrons)

No. of personnel	Rating
1	ATCS
2	ATC
5	AT1
12	AT2
8	AT3 and below

Table I

Utilizing the average billet structure, yearly maintenance personnel training costs were computed for all of the alternatives and are displayed in Table II. The computations are presented in Appendix B.

ORGANIZATIONAL	
Minicomputer	\$233,451
Microcomputer - alt. 2	\$ 55,363
Microcomputer - alt. 3	\$ 55,363
INTERMEDIATE	
Minicomputer	\$ 34,333
Microcomputer - alt. 2	\$ 34,333
Microcomputer - alt. 3	\$ 34,333

Table II

The intermediate maintenance requirements are a direct result of the organizational requirements. The modules removed at the organizational level will be sent to intermediate maintenance for repair.

The amount of maintenance time is traditionally computed through the use of mean-time-between-failure (MTBF) and mean-time-to-repair (MTR) rates. The figures used in this study are an aggregate of industry available data on commercially manufactured mini and micro computers [8, 12, 13, 14, 15, 16]. The aggregate figures are listed in Table III.

	MINI (HRS)	MICRO (HRS)
ORGANIZATIONAL		
MTR	2	1
MTBF	1200	25,000
INTERMEDIATE		
MTR	2	2
MTBF	1200	25,000

Table III

The difference in MTR at the organizational level is attributable to the fact that the microcomputer, in whole, will be removed and replaced, while the minicomputer must be troubleshot until the failing module is isolated.

Yearly maintenance personnel costs, based on the figures in Tables II and III, were computed and are listed in Table IV. The computations are presented in Appendix B.

Organizational		
	Minicomputer	\$2,251
	Microcomputer - alt. 2	\$ 540
	Microcomputer - alt. 3	\$ 540
Intermediate		
	Minicomputer	\$2,323
	Microcomputer - alt. 2	\$1,115
	Microcomputer - alt. 3	\$1,115

Table IV

III. Support Equipment Maintenance
A. Organizational
B. Intermediate

The use of a microcomputer system would require that each aircraft squadron, the organizational level, maintain a piece of equipment to program the memory IC's of the computer. This equipment is unnecessary in the case of the minicomputer due to the use of a different memory chip.

This assumes that the microcomputer utilizes an eraseable programmable memory (EPROM), which would facilitate field changes in the operating system as required. The memory in the minicomputer can facilitate changes without any special equipment.

At the intermediate level of maintenance, the requirements are independent of the choice of computer system. It is necessary to maintain a logic tester to isolate faults in both the cases, either a minicomputer module, or an entire microcomputer. This is required due to the high complexity of both IC and LSI technologies.

Yearly support equipment maintenance costs, computations displayed in Appendix B, are listed in Table V.

Organizational		
	Minicomputer	$ 0
	Microcomputer - alt. 2	$2,100
	Microcomputer - alt. 3	$2,100
Intermediate		
	Minicomputer	$7,500
	Microcomputer - alt. 2	$7,500
	Microcomputer - alt. 3	$7,500

Table V

The cost elements included in computations to this point clearly favor the microcomputer avionics system, with no differentiation between alternatives 2 and 3, the homogeneous and heterogeneous systems respectively. The last cost element to be considered is the cost of spare parts, at the intermediate level, and will be restricted to those applicable to the microcomputer systems.

The individual IC and LSI costs for modular repair are minimal and comparable in cost for each of the alternatives. The purpose of this discussion is to compare repair costs with off-the-shelf replacement costs, thereby possibly eliminating the need for intermediate maintenance. The individual module/board cost for minicomputers each exceed $1,000 and can therefore not be considered consumable items [11, 12]. The cost for microcomputer modules averages $500 each, and are thus a viable consideration for disposal versus repair. The costs to be considered are individual module cost and inventory holding costs, as compared to the sum of intermediate maintenance costs.

IV. Spare parts - intermediate level only

The calculation of discard versus repair figures in the microcomputer systems is only valid for the homogeneous alternative. The costs figures to this point are identical in both alternatives 2 and 3. The heterogeneous alternative, #3, would require an increased supply inventory problem due to the fact that ten different computers would have to be stocked in sufficient supply to only one in the case of the homogeneous alternative, #2. Although inventory is not a subject examined in this study it will be assumed that the additional associated costs with alternative #3 would prove repair a more cost effective alternative.

The figure computed for yearly spare parts required in a discard situation are presented in comparison to the total yearly intermediate maintenance costs for the microcomputer systems in Table VI.

Differential Spares	$34,749
Intermediate maintenance costs	$42,948

Table VI

The computation of the above figures directly leads to a comparison of all three alternatives yearly costs displayed in Table VII.

COST ELEMENT	MINI	MICRO (HOMO)	MICRO (HETERO)
I. MAINTENANCE TRAINING			
A. ORGANIZATIONAL	$233,451	$55,363	$55,363
B. INTERMEDIATE	$ 34,333	$ 0	$34,333
II. MAINTENANCE PERSONNEL			
A. ORGANIZATIONAL	$ 2,251	$ 540	$ 540
B. INTERMEDIATE	$ 2,323	$ 0	$ 1,115
III. SUPPORT EQUIPMENT MAINTENANCE			
A. ORGANIZATIONAL	$ 0	$ 2,100	$ 2,100
B. INTERMEDIATE	$ 7,500	$ 0	$ 7,500
IV. DIFFERENTIAL SPARES	$ 0	$34,749	$ 0
YEARLY TOTALS	$279,858	$92,752	$100,951

Table VII

The above figures represent the total costs of each alternative for a one year period. In order to calculate the total Life Cycle Cost of each, the totals for an eight year period, previously identified as the ADPE life cycle, must be computed in conjunction with the application of a 10% discount rate (Assumption 11). This procedure is outlined in Appendix B. The figures in Table VIII represent the results of that computation.

ALTERNATIVE	LIFE CYCLE COST
MINICOMPUTER	$1,642,324
MICROCOMPUTER (homogeneous)	$ 544,308
MICROCOMPUTER (heterogeneous)	$ 592,423

Table VIII

The Life Cycle Cost totals presented clearly favor the choice of one of the two microcomputer systems over the minicomputer system. The approximate $50K difference between the two microcomputer alternatives was computed on the basis of only six aircraft squadrons and one intermediate maintenance facility. The same computations applied to a Navy-wide avionics program would result in a considerably higher figure, while still maintaining the identical relative percentage of the total cost. This point will be further examined in the next chapter.

VII. ANALYSIS AND CONCLUSIONS

A. ANALYSIS

There are several significant points about the methodology and computations previously presented that are worthy of mention.

(1) The comparison of the three alternatives in the context of maintenance personnel and training costs has been accomplished through the use of "a fortiori" analysis. The figures used for MTBF and MTR for minicomputers are optimistic at the organizational maintenance level. Actual experience, as discussed by Refs. 8 and 15, has shown that the MTR can vary from one hour to one week, depending on the individual problem. A higher figure would only bias the computations more favorably for the microcomputer alternatives. On the other hand, the MTBF figures used for the microcomputer computations are pessimistic. The literature on microcomputers shows that a MTBF range of 25,000 to 130,000 hours is available, depending on various designs [22]. Again, a bias in favor of the minicomputer.

(2) The MTR figures at the intermediate maintenance level reflect the assumption that logic test stations are available for modular/board checkout. These stations are programmable machines that check out hardware through the use of software tests and average one hour of testing per module. Testers are being used in commercial industry extensively. This assumption does not bias the computations in the mini versus

micro argument, but is the basis for the difference between alternatives two and three, the homogeneous and heterogeneous systems respectively. The absence of such a test station would cause an increase in the MTR, making the discard decision more cost effective in the case of the homogeneous system. This would cause a greater total cost difference between the homogeneous and heterogeneous systems, favoring the homogeneous one.

(3) The maintenance training requirement at the organizational level is the largest differential factor in all three alternatives. If the requirements for a minicomputer system were identical to those of the microcomputer, or vice versa, alternative 2, the homogeneous microcomputer, would still be the least cost alternative, but by a much smaller margin. The only difference would be the savings produced by the discard decision over repair. An increase in training length would make the heterogeneous system the most costly, requiring training on ten individual systems. The training course length figures used in this study are based on many years experience with both civilian and military technicians at Fleet Numerical Weather Central in the computer field [8, 15]. They also coincide with present industry recommendations and are believed to be accurate estimates.

(4) The assumption of no inflation and the use of a 10% discount rate only affected the overall cost figures, while having no effect on the ranking of cost effective alternatives. This is evident in the yearly cost totals, by noting that the

absolute difference between alternatives is equivalent for each year.

(5) As discussed in Appendix B, the MTBF was assumed to be a linear function in the discard versus repair figures. The use of a traditional exponential function would lower the total failures estimated during the life cycle, proving the discard an even more effective choice.

(6) The use of a 1:10 ratio between minicomputers and microcomputers may be an overestimation. This figure equates the absolute computing power of each. At the time of this writing the proper ratio was not determined, but if anything, would prove that fewer microcomputers are necessary.

(7) The use of all E-5 and above billets at the organizational and intermediate maintenance levels for the computation of total training costs and manhour costs is common to all alternatives [4].

(8) The exclusion of operator training in the total LCC calculations may not be a valid assumption in the minicomputer case. This is dependent on the particular system chosen. The addition of this element would only bias the microcomputer alternatives more favorably.

(9) The discard versus repair discussion is based on a $500 modular cost. This is an actual figure obtained from Ref. 13. This is a current cost figure that should decrease with large purchases and over time with technological advances. The costs of IC's and LSI's have decreased by an order of magnitude in the past few years, which should be indicative of the future.

(10) The training requirements were averaged out on a yearly basis, with the assumption of a continuous need for training. This assumption appears valid in the area of avionics ADPE as each aircraft type would have a different system depending on the application. A change in this assumption would affect all alternatives.

B. CONCLUSIONS

The comparison of the three alternatives in the context of manpower and training requirements clearly favors the use of a federated microcomputer system in lieu of a centralized minicomputer system. The associated Life Cycle Cost computations produce nearly a 3:1 ratio favoring the microcomputer alternatives.

The comparison of a homogeneous versus heterogeneous microcomputer system does not yield such conclusive results. An approximate ratio of 11:12 in favor of the homogeneous system was formulated. This small difference is reflected in the choice of discard over repair at the intermediate maintenance level. This difference may only serve as an input to a total LCC computation involving all of the elements as outlined in Appendix A. The investment and supply elements may prove more conclusive in determining the proper decision criteria.

The discard decision was based on purely economic considerations, with other possible benefits ignored. The use of an All Volunteer Force has caused, in some cases, severe manpower shortages for all of the armed services. The highly

technical ratings, such as the Aviation Electronics Technician rating, have been most affected by this shortage. Any possible reduction in the future manpower requirements, which may be possible as well as economically sound in the discard decision, would ease the overall manpower problems being experienced.

The choice of microcomputers over minicomputers may not be an entirely economical decision. The benefits of design and engineering as well as performance characteristics must be examined prior to reaching a final decision.

The determination of initial investment costs substantiates the choice of microcomputers over minicomputers, with an approximate 2:1 ratio existing between the systems respectively. These figures are based on currently available military versions of each. The use of a militarized version greatly increases the investment costs due to the stringent military specifications, but has little or no effect on the maintenance and manpower costs formulated in this study. Corresponding decreases in equipment costs would be relative to all alternatives, not affecting the overall ranking of costs.

APPENDIX A

COST ELEMENT STRUCTURE

- 1.0 Research and Development
  - 1.1 Concept and Validation
    - 1.1.1 Contractor
    - 1.1.2 Government
  - 1.2 Full Scale Development (FSD)
    - 1.2.1 Contractor
      - 1.2.1.1 Program Management
      - 1.2.1.2 Engineering
      - 1.2.1.3 Fabication
      - 1.2.1.4 Contractor Development Tests (CDT)
      - 1.2.1.5 Test Support
      - 1.2.1.6 Producibility Engineering and Planning (PEP)
      - 1.2.1.7 Data
        - 1.2.1.7.1 Engineering Data
        - 1.2.1.7.2 Support Data
        - 1.2.1.7.3 Management Data
        - 1.2.1.7.4 Technical Orders and Manuals
      - 1.2.1.8 Peculiar Support and Test Equipment
      - 1.2.1.9 Other
      - 1.2.1.10 General and Administrative
      - 1.2.1.11 Fee
    - 1.2.2 Government
      - 1.2.2.1 Program Management
      - 1.2.2.2 Test Site Activation
      - 1.2.2.3 Government Tests (DTE/IOTE)
      - 1.2.2.4 Government Furnished Equipment (GFE)
      - 1.2.2.5 Other

COST ELEMENT STRUCTURE

Source: TRI-TAC

2.0 Investment (Non-Recurring)
- 2.1 Contractor
  - 2.1.1 Program Management
  - 2.1.2 Producibility Engineering and Planning (PEP)
  - 2.1.3 Initial Production Facilities (IPF)
    - 2.1.3.1 Production Engineering
    - 2.1.3.2 Tooling
    - 2.1.3.3 Industrial Facilities
    - 2.1.3.4 Manufacturing Support Equipment
  - 2.1.4 Technical Support
  - 2.1.5 Initial Spares and Repair Parts
  - 2.1.6 Initial Training
    - 2.1.6.1 Training Facilities
    - 2.1.6.2 Training Devices and Equipment
    - 2.1.6.3 Initial Student Training
      - 2.1.6.3.1 Operator Training
      - 2.1.6.3.2 Maintenance Training
      - 2.1.6.3.3 Instructor Training
  - 2.1.7 Data
    - 2.1.7.1 Engineering Data
    - 2.1.7.2 Support Data
    - 2.1.7.3 Management Data
    - 2.1.7.4 Technical Orders and Manuals
  - 2.1.8 Leaseholds
  - 2.1.9 Common Support Equipment
  - 2.1.10 Peculiar Support and Test Equipment
  - 2.1.11 Other Non-Recurring Costs
  - 2.1.12 General and Administrative
  - 2.1.13 Fee or Profit

2.2 Government (Non-Recurring)

2.2.1 Program Management

2.2.2 Initial Training

2.2.2.1 Training Facilities

2.2.2.2 Training Devices and Equipment

2.2.2.3 Initial Student Training

2.2.2.3.1 Operator Training

2.2.2.3.2 Maintenance Training

2.2.2.3.3 Instructor Training

2.2.3 Production Acceptance Test and Evaluation (PATE)

2.2.4 Operational Test and Evaluation (OTE)

2.2.5 Test Site Activation

2.2.6 Government Furnished Equipment (GFE)

2.2.7 Other Non-Recurring Investment Costs

3.0 Investment (Recurring)
  3.1 Contractor
    3.1.1 Manufacturing
    3.1.2 Production Material
      3.1.2.1 Purchased Equipment and Parts
      3.1.2.2 Subcontracted Items
      3.1.2.3 Other Material
    3.1.3 Sustaining Engineering
    3.1.4 Quality Control and Inspection
    3.1.5 Packaging and Transportation
    3.1.6 Operational/Site Activation
      3.1.6.1 Site Construction
      3.1.6.2 Site/Ship/Vehicle Conversion
      3.1.6.3 Assembly, Installation and Checkout
    3.1.7 Other Recurring Investment Costs
    3.1.8 General and Administrative Costs
    3.1.9 Fee or Profit
  3.2 Government (Recurring)
    3.2.1 Quality Control and Inspection
    3.2.2 Sustaining Engineering
    3.2.3 Transportation
    3.2.4 Operational/Site Activation
      3.2.4.1 Site Construction
      3.2.4.2 Site/Ship/Vehicle Conversion
      3.2.4.3 Assembly, Installation and Checkout
    3.2.5 Technical Orders and Manuals
    3.2.6 Government Furnished Material
    3.2.7 Other Recurring Cost

4.0 Operating and Support Costs (O&S)

- 4.1 Operations
  - 4.1.1 Electrical Power
  - 4.1.2 Special Materials
  - 4.1.3 Operator Personnel
  - 4.1.4 Operational Facilities
  - 4.1.5 Equipment Leaseholds
  - 4.1.6 Other Operations Costs
- 4.2 Logistic Support
  - 4.2.1 Maintenance
    - 4.2.1.1 Personnel
      - 4.2.1.1.1 Organizational Maintenance Personnel
      - 4.2.1.1.2 Intermediate Maintenance Personnel
      - 4.2.1.1.3 Depot Maintenance Personnel
    - 4.2.1.2 Maintenance Facilities
    - 4.2.1.3 Support Equipment Maintenance
    - 4.2.1.4 Contractor Services
  - 4.2.2 Supply
    - 4.2.2.1 Personnel
      - 4.2.2.1.1 Organizational Supply Personnel
      - 4.2.2.1.2 Intermediate Supply Personnel
      - 4.2.2.1.3 Depot Supply Personnel
    - 4.2.2.2 Supply Facilities
    - 4.2.2.3 Spare Parts and Repair Material
    - 4.2.2.4 Inventory Administration
      - 4.2.2.4.1 Inventory Management
      - 4.2.2.4 2 Inventory Holding
    - 4.2.2.5 Transportation and Packaging
  - 4.2.3 Other Logistic Support Costs

APPENDIX B

Life Cycle Cost Calculations

I. Maintenance Training

The economic cost of training military personnel includes the following cost elements: [3]

(1) Annual billet cost
(2) Travel cost for specialized training
(3) Replacement training cost
(4) Specialized training cost
(5) Support costs

Cost Formula

Maintenance Training Cost (MTC) = 1+2+3+4+5

Cost Factors	Basis
Annual billet cost*	Bureau of Naval Personnel PERS-21221 [5]
Travel cost for specialized training	$33/day per diem + $500 travel (average)
Replacement training cost	DCA Circular 600-60-1 [5]
Specialized training cost	$500/week tuition [11, 16]
Support costs**	CNO Budget Data FY 76 [4]

*Includes base pay, hazard duty pay, FICA, constant pay grade (BAQ, FSA, clothing allowance, government quarters), pro pay (sea, foreign duty, proficiency), constant cost per year (admin, subsistence, life insurance), school cost (support), PCS travel, settlement cost (severance, terminal leave, reenlistment bonus), retirement contribution.

**This cost element represents an allocated portion of medical and base operations support costs financed by operation and maintenance (O&MN) appropriations which are not otherwise included as part of the economic cost.

Economic Cost Calculation

I. Maintenance Training

A. Minicomputer

1. Organizational level

Training duration - 8 weeks
Per diem duration - 56 days
Rate and number of trainees per squadron: ATC=1, AT1=3, AT2=8

MTC = maintenance training cost
MTC = 1+2+3+4+5

where:

1 = annual billet cost =	$23,831/year (for ATC)
2 = travel cost =	$33/day @ 56 days + $500
3 = replacement training =	$3,755/year
4 = specialized training =	$500/week @ 8 weeks
5 = support costs =	$505/year

MTC_C = maintenance training cost for ATC

MTC_C = ($23,831) (8wks/52wks/1yr) = $2,348 + ($3,755) (8wks/52wks/yr) + $4,000 + ($505) (8wks/52wks/yr)
= $10,669.69

MTC_1 = maintenance training cost for AT1
= $10,003.07 X (3 AT1s per squadron) = $30,009.22

MTC_2 = maintenance training cost for AT2
= $9,505.84 X (8 AT2s per squadron) = $76,046.73

Total MTC = $MTC_C + MTC_1 + MTC_2$

= $116,725.64

divide the total MTC by 3 year tour length to obtain a yearly training figure:

= $38,908.55/year/squadron

Total for six squadrons = $233,451.30/year

2. Intermediate level

Training duration - 7 weeks
Per diem duration - 49 days
Rate and number of trainees per department: ATCS=1, ATC=2, AT1=5, AT2=12

Utilizing the same methodology in I.A.1. above, the following total was computed:

Total for one maintenance department = $34,333/year

I. Maintenance Training
B. Microcomputer
1. Organizational level

Training duration - 2 weeks
Per diem duration - 14 days
Rate and number of trainees per squadron: ATC=1, AT1-3, AT2=8

Utilizing the same methodology as in I.A.1, the following total was computed:

Total for six squadrons = $55,362.84/year

2. Intermediate level

The figures for this cost calculation are identical to those computed for the minicomputer.

Total for one maintenance department = $34,333/year

The figures for microcomputer maintenance training are assumed to apply to both alternatives two and three. This is justified by the fact that the training is of a general nature for microcomputers, with no specific training on a particular system. If the federated heterogeneous system, alternative 3, was composed of hardware not physically related, this would not be a valid assumption with a corresponding increase in required training.

II. Maintenance Personnel

The TRI-TAC office [3] has developed a cost formula to calculate the cost of this element, consisting of the following elements:

(1) Preventative maintenance time

(2) Corrective maintenance time

(3) Manhour cost

(4) Quantity of operational equipment

where

(2) Corrective maintenance time = number of operating hours per year (A) multiplied by the quotient of mean time to repair (B) divided by mean time between failures (C).

<u>Cost Formula</u>

Maintenance Personnel Cost (MPC) = ((1)+(A)(B/C)) X (3) X (4)

<u>Cost Factors</u>	<u>Basis</u>
Preventative maintenance time	zero, assumption 2
Corrective maintenance time	
No. of operating hour per year	2340, assumption 9
MTBF	CDC,ROLM Cor., Hughes Aircraft Cor. [14, 11, 12, 13]
MTR	FNWC (Eng. and Maint. Div's.)
Manhour Costs*	BUPERS-21221
Quantity of operational equipment	54, assumption 5

*The manhour cost will be computed in the following manner:

1.	52 weeks x 40 hr week =	2080
	30 days leave plus 9 holidays or the equivalent of 6 normal 40 hr weeks =	-240
	Subtotal	1840
	10% loss (sickness, tests, etc.)	-184
	TOTAL AVAILABLE MANHOURS	1656

*continued

2. 1 x ATC annual billet cost $ 23,831
   3 x AT1 annual billet cost $ 58,494
   8 x AT2 annual billet cost $130,128

1 x ATC	annual billet cost	\$ 23,831
3 x AT1	annual billet cost	\$ 58,494
8 x AT2	annual billet cost	\$130,128
	TOTAL	\$212,453

$$\frac{\$212,453}{\text{sum of ATC+AT1+AT2}} = \frac{\$212,453}{(1+3+8)} = \frac{\$212,453}{12} = \$17,704.42$$

$$\frac{\$17,704.42}{\text{Total available manhours}} = \frac{\$17,704.42}{1656} = \$10.69/\text{hour}$$

3. Intermediate manhour costs

1 x ATCS	annual billet cost	\$ 25,066
2 x ATC	annual billet cost	\$ 47,662
5 x AT1	annual billet cost	\$ 97,490
12 x AT2	annual billet cost	\$195,192
	TOTAL	\$365,410

$$\frac{\$365,410}{\text{sum of ATCS+ATC+AT1+AT2}} = \frac{\$365,410}{(1+2+5+12)} = \frac{\$365,410}{20} = \$18,270.50$$

$$\frac{\$18,270.50}{\text{Total available manhours}} = \frac{\$18,270.50}{1656} = \$11.03/\text{hour}$$

Economic Cost Calculation

II. Maintenance Personnel
  A. Minicomputer
    1. Organizational level

MPC - maintenance personnel cost

Operating hours/year	195 hours/month X 12 months = 2340 hours
MTR	2 hours
MTBF	1200 hours
Manhour cost	\$10.69/hour
Quantity of equipment	9 aircraft X 1 computer X 6 squadrons = 54

MPC = (2340 X 2/1200) X (10.69) X 54 = \$2,251.51/year

2. Intermediate level

Operating hours per year	2340 hours
MTR	2 hours
MTBF	1200 hours
Manhour cost	\$11.03/year
Quantity of equipment	54

Utilizing the same formula as above

MPC = \$2,322.92/year

II. Maintenance Personnel

B. Microcomputer

1. Organizational level

Operating hours per year	2340 hours
MTR	1 hour
MTBF	25,000 hours
Manhour cost	$10.69/hour
Quantity of equipment	9 aircraft X 10 computers X 6 squadrons = 540

Utilizing the formulation previously presented

MPC = $540.32/year

2. Intermediate level

Operating hours per year	2340 hours
MTR	2 hours
MTBF	25,000 hours
Manhour cost	$11.03/hour
Quantity of equipment	540

Utilizing the formulation previously presented

MPC = $1,115.00/year

III. Support Equipment Maintenance

Historical data analysis has shown that the cost of support equipment maintenance can be approximated by the use of a factor of 10% of the equipment cost per year [23]. The TRI-TAC office [3] has developed a formula to calculate the cost of this element, containing the following cost elements:

(1) Support equipment maintenance factor

(2) Cost of support equipment

<u>Cost Formula</u>

Support equipment maintenance cost (SEMC) = 1 + 2

Cost Factors	Basis
Support equipment maintenance factor	TRI-TAC [3]
Cost of support equipment	Fluke and Prologue, Inc. [21]

III. Support Equipment Maintenance

A. Minicomputer

1. Organizational level

No specific support equipment required	$ 0

2. Intermediate level

Support equipment maintenance factor	10%
Cost of support equipment	$75,000

SEMC = (.10) X $75,000 = $7,500/year

B. Microcomputer

1. Organizational level

Support equipment maintenance factor	10%
Cost of support equipment	$3,500 X 6 = $21,000

SEMC = $2,100/year

2. Intermediate level

The requirement at the intermediate level is identical to that of the minicomputer.

SEMC = $7,500/year

IV. Spare Parts

The determination of module replacement costs per year is complicated by the high MTBF for the microcomputers. A reverse computation will be used to determine a breakeven point whereby module discard cost equals intermediate maintenance cost. A factor of 25% of purchase cost is traditionally used for inventory holding cost in government calculations.

Cost Formula

Module replacement cost (MRC) = (cost per module) X (1 + inventory holding cost)

Cost Factors

Cost per module	\$500 [13]
Inventory holding cost	25%

The only computation will be for the microcomputer at the organizational level. This will be an input to a possible discard versus repair decision, eliminating the need for intermediate maintenance for the microcomputer. (alt 2)

Total of intermediate maintenance costs:

Maintenance training	\$34,333
Maintenance personnel	\$ 1,115
Support equipment maintenance	\$ 7,500
	\$42,948

MRC = (\$500) X (1.25) = \$625/module

Dividing this cost into the yearly intermediate maintenance cost yields:

(42,948/\$625) = approx. 69 modules per year (68.72)

The failure rate per year will be approximated by assuming that the MTBF is a linear function, for simplicity in calculations.

MTBF = 25,000 hours = .00004/hour

Total operating hours = 195/month X 12/months = 2340/year

Failure rate = (2340)(.00004)(10/aircraft)(9 aircraft/squardon)

X (6 squadrons) = 51 failures/year

Comparing the failure rate with the break even point computed:

Failure rate = 51/year

Break even point = 69/year

Note; 69 = 135% X 51

Drawing some conclusions, the failure rate could exceed the predicted failure rate by as much as 35% and discarding the unserviceable modules would be more cost effective than performing intermediate maintenance. The computation of a yearly figure for the replacement cost is computed by multiplying the failure rate by the module replacement cost. An additional 10% failures will be added to allow for deviations.

Spare Parts Cost = (MTBF)(1.1) X (total operating hours)

X (number of computers) X (MRC)

= (.00004)(1.1)(195X12)(540)(625)

= $34,749/year

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